A New Look at Stratospheric Sudden Warmings. Part II. Evaluation of Numerical Model Simulations

Andrew Charlton, Lorenzo Polvani, Judith Perlwitz, Fabrizio Sassi, Elisa Manzini, Kiyotaka Shibata, Steven Pawson, Eric Nielsen, David Rind

Abstract

The simulation of major, mid-winter, stratospheric sudden warmings (SSWs) by six, stratosphere-resolving general circulation models (GCMs) is examined. The GCMs are compared to a new climatology of SSWs, based on the dynamical characteristics of the events. Firstly, the number, type and temporal distribution of SSW events is evaluated. Most of the models show a lower frequency of SSW events than the climatology, which has a mean frequency of 6.0 SSWs per decade. Statistical tests show that three of the six models produce significantly fewer SSWs than the climatology, between 1.0 and 2.6 SSWs per decade. Secondly, four process-based diagnostics are calculated for all of the SSW events in each model. SSWs in the GCMs compare favorably with dynamical benchmarks for SSW established in the first part of the study.

The results of these two sets of tests indicate that GCMs are capable of simulating the dynamics required to produce SSWs, but with lower frequency than the climatology. Further dynamical diagnostics hint that, in at least one case, this is due to a lack of meridional heat flux in the lower stratosphere. Even though the SSWs simulated by most GCMs are dynamically realistic when compared to the NCEP/NCAR reanalysis, the reasons for the relative paucity of SSWs in GCMs remains an important and open question.

Popular Summary

Sudden warmings are characterized by somewhat dramatic departures from normality of the high-latitude stratospheric circulation, with rapid increases in temperature in the polar region and sudden decelerations of the wind in middle latitudes. In terms of the stratospheric polar vortex, a strong cyclonic circulation that dominates the circulation in winter, warmings can take two forms – either a displacement of the vortex from the pole or a split into two pieces (these are often referred to as Wave-1 and Wave-2 warmings, or vortex displacements and vortex splits).

Warmings are important for ozone loss. In cold winters, with no warmings, air may be confined to the polar region for many weeks. The exposure of these air masses to low temperatures leads to denitrification and possibly dehydration; in turn, this can lead to activation of catalytic chlorine reactions that deplete ozone when the sun returns in spring. When sudden warmings occur, the temperature of the polar region is higher so these chemical processes are less common. There can also be substantial mixing between polar and middle latitudes. The existence, or not, of ozone loss in the Arctic stratosphere is thus intimately connected to the occurrence of warmings.

Climate models are used to understand processes that can explain the evolution of past climate, as well as to predict the future climate change. An important factor in assessing the validity of future climate predictions is whether or not a model can successfully represent various aspects of the past. In this context, the validity of a model's prediction of the future evolution of ozone and climate may be given some degree of certainty, according to how well that model can represent the past record, when observations exist. Because of the links between polar ozone and sudden warmings, one important metric of model performance is the adequacy of simulation of these events: how frequently they occur, how they are forced, and how realistically the different types of event (vortex splits and vortex displacements) are represented.

The present paper compares such statistics from six models, all of which have been applied to the problem of understanding ozone change. The models display a wide range of behaviors, but half of them simulate warming events with frequency and characteristics that are statistically indistinguishable from the observed record. The GEOS-4 GCM is one of the better performing models, a fact that lends credence to our application of this model to coupled chemistry-climate problems.